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A framework for benchmarking greenhouse gas emissions intensity in Scottish farming

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Executive summary

One way to reduce the carbon footprint of the food we produce is to use more efficient methods in agriculture, but we also need to gather information on what works best and how we are getting better.

This research was designed to develop a robust method for generating emissions intensity data on Scottish farms. We wanted to be able to generate an estimate for individual farm businesses, and also scale up to a Scotland level, and to be able to repeat the process so that improved performance could be recorded. Beginning with beef production, we compared existing methods to find out what might work best, and gathered together a list of existing datasets that are already collected.

We then designed a framework that could begin to calculate the intensity of the emissions – that is, the amount of emissions per unit of production (for example, per kilo of beef). The framework is strengthened by using existing tools that have been widely tested (AgRE Calc and Solagro Carbon Calculator), which should avoid an additional administrative burden on farmers.

We concluded that there is considerable potential for the framework to generate an estimate of emissions intensity, although more detailed information across a wider range of farms will improve its robustness. For example, we used data collected under the Scottish Government's Beef Efficiency Scheme (BES) for this project, but additional information may be needed at a farm level to ensure that all types of beef production in Scotland can be included. The continued availability of tools is important to the implementation of the framework. Resources are needed to maintain and continue the development of good carbon footprinting tools[1]

Implementation of the framework, and expansion to cover other food production sectors, could help to lower the emissions associated with food production. This will require an extension of the comparative analysis to identify suitable tools that can be applied to other sectors of agriculture, such as arable farming or soft fruit production

[1] Note linked project: ClimateXchange report "Comparative analysis of farm-based carbon audits" I. Leinonen, V. Eory, M. MacLeod, A. Sykes, K. Glenk and R. Rees https://www.climatexchange.org.uk/research/projects/comparative-analysis-of-farm-based-carbon-audits/

Content

1. Introduction

The aim of this project was to develop a robust and repeatable method, suitable for use by Scottish farm businesses, for generating emissions intensity data on Scottish farms. Emissions intensity is defined here as the mass (e.g. kg or tonne) of greenhouse gases (GHGs in units of carbon dioxide equivalent, CO_2e) produced per unit mass (e.g. kg or tonne) of output, such as each kilogramme of beef or each litre of milk.

There is a need for the agriculture sector in Scotland to contribute to global reductions in greenhouse gas (GHG) emissions to minimise significant climate impacts. However, agriculture has unique GHG mitigation challenges due to the unavoidable biochemical processes associated with production systems.

Inventories of GHGs focus on absolute emissions within defined geographic boundaries, but do not account for the production (e.g. of goods or services) that is associated with the emissions. The use of GHG emissions intensity as a measure for GHG emissions focusses attention on efficiency, or quantity of production per quantity of emissions. This allows comparison with emissions intensity of production by alternative methods, or in alternative locations. It also allows emissions to be related to consumption, and therefore can help to avoid unintended consequences such as emissions leakage when food is imported, and the production emissions occur outside the geographic boundary of the Scotland inventory.

Scottish Government has ambitions to be among the ‘lowest carbon’, most efficient producers in the world. This project will help to inform the decision-making process for delivery of this commitment. To provide evidence for the ‘carbon’ efficiency of production, and to measure improvement, a robust methodology for the measurement of GHG emissions intensity is necessary. This is recognised in the Scottish Government’s Climate Change Plan (The Third Report on Proposals and Policies 2018-2032, February 2018), which requires a “report into the establishment of emissions intensity figures for beef, lamb and milk”.

In the Climate Change Plan, the Scottish Government has made a commitment to reduce the carbon footprint of the food we produce, by lowering the emissions associated with food production. This research will examine how to inform the decision-making process for delivery of this commitment.

Project tasks are described in Appendix 1, and comprised:

- Comparative analysis of existing methods for carbon intensity assessment,
- Compile existing datasets,
- Development of assessment framework.

2. Comparative analysis of existing methods for carbon intensity assessment

Introduction

This independent analysis compares available methods and tools that can be used for benchmarking GHG emissions intensity. We present the key attributes and suitability for Scottish beef farming.

Method

Carbon footprinting methods were identified using our team knowledge of available tools and methods, supported by internet searches and searches of academic papers and conference proceedings. The identified methods were evaluated against a list of essential criteria, in the form of questions that that could be answered yes or no. These simple questions were based on the requirements to assess GHG emissions intensity for multiple beef farm enterprises in Scotland, from cradle to gate, i.e. the lifecycle including raw materials for production through the production on farm, as far as the farm gate where a product is ready for sale. The criteria were as follows.

- Is the tool and adequate documentation available?
- Is the tool applicable to the beef sector?
- Activity data is available or can be collected?
- Are emission factors provided, or available?
- Lifecycle approach?
- Useable by a farm advisor in a reasonable time?
- Suitable for cradle to farm gate assessment?
- Carbon footprint per unit of production?
- Are all major sources of emissions are included?

A negative outcome against any criterion resulted in exclusion from a short list of methods that was tested further by entering a set of activity data. The activity data set used was developed by a livestock systems expert using results from previous work with the beef sector in Scotland.

Results

1.1.1 The methods and tools identified

We identified 17 methods for assessment and these are listed in Table 6 (see Appendix 3, section 0). The methods were a mix of written methods and software tools.

1.1.2 High-level comparison

The results of the evaluation of carbon footprinting methods against essential criteria are given in Appendix 4. The evaluation resulted in a short list of three methods:

- Agricultural Resource Efficiency Calculator (AgRE Calc)
- Cool Farm Tool (CFT)
- Solagro Carbon Calculator (Solagro CC)

Each of these methods passed were accepted on the basis of the criteria given in section 0 above. Details about these methods is given in Appendix 3 (section 0).

1.1.3 Testing with farm data

Testing of the tools for the purposes of comparing functionality and user experience was undertaken using a standard set of notional farm data developed using results from previous work with the beef sector in Scotland. The purpose was to test the usability of the tools, not to check the validity of the tool outputs.

Some tabulated information on the user experience with each of the three tools is given in Appendix 5 (section 10).

The interface for AgRE Calc was in a simple, tabular format, using a web-based platform that steers the user through a series of logical data entry tables. Overall the data requested should be obtainable by a farmer with a reasonable approach to record keeping, but there were areas that may cause some farmers difficulties, including for fuel and energy usage allocation to enterprises, and grassland crop removals by grazing. It is unclear from the guidance what is included in sequestration estimates, but it appears only to be the sequestration from Farm woodland. Output data can be reported in multiple ways including as a GHG intensity value in kg CO_2e/kg of output, for both liveweight and deadweight. The reporting structure gives an option to view comparative data which provides benchmarking opportunities.

The Cool Farm Tool interface was easy to use, but the need to separate out forage crops into a separate analysis caused confusion. This made problems for determining enterprise emissions as there were separate outputs for the same beef enterprise, and the aggregation function did not appear to work. Otherwise the reporting structure was clear. The report provided:

- Emissions per unit liveweight (kg CO_2e/kg)
- Total Farm emissions (kg CO_2e)
- A breakdown of GHG by source and gas

The user interface for Solagro CC used Microsoft Excel, but was not well designed. Non-experts in Excel had difficulty getting the settings right to run the Excel macros. However, the tool appeared to capture all the required input data. It went further than the other two tools on carbon sequestration relating to hedgerows and other woody biomass, although it was not clear how that information was used. The output data were disaggregated usefully to give emissions by process, such as enteric fermentation and manure management.

Table 1 provides the results from each carbon footprinting exercise which should be treated as indicative for an upland beef suckler system, with progeny sold at weaning. The data do not provide an indication of the carbon intensity for finished beef cattle at the farm gate. Furthermore, it is not possible, without an assessment of lifecycle emissions from first principles, to determine which tool produced the most accurate or precise results.

Table 1. Results comparisons from three carbon footprinting tools.

	AgRE Calc	Cool Farm Tool	Solagro CC
GHG emissions (kg CO_2e/kg deadweight)*	59.67	-	-
GHG emissions (kg CO_2e/kg liveweight)	31.63**	7***	22.34
Total farm emissions (kg CO_2e)	625,712	581,830	665,380
Emissions per ha (kg CO_2e)	6159	5704	6460

*Deadweight calculations are assumed in this example as animals are sold store (to be finished on another holding) Refer to 1.1.7 for farm systems explanations.

**The output from the AgRE Calc appears to underestimate output meaning GHG intensity is higher than expected.

***Due to a significant over estimation of output (kg beef) 83,085 vs 27,635. The Cool Farm Tool appears to be calculating output incorrectly by including breeding stock in output figures.

The notional farm was a 100-cow upland beef suckler system, with spring calving and progeny sold at weaning. The results given in Table 1 indicate that the three tools produce numerical results that are of the same order of magnitude, and that are closer on an area basis (emissions per ha) than on an emissions intensity basis (emissions/kg liveweight). This is because for the latter, estimation of production is an additional source of error.

Because beef production from breeding of calves through to slaughter for meat does not always occur on a single farm and some calves are bred for finishing at other farms, an estimate of emissions intensity needs to take account of this movement between farms. However, none of the three carbon footprinting tools included embedded emissions in livestock bought from another farm.

1.1.4 SWOT analysis

In Appendix 6 (section 11), analyses of strengths, weaknesses, opportunities and threats (SWOT) are presented for AgRE Calc, The Cool Farm Tool and Solagro CC respectively.

Each of these tools has useful strengths and opportunities. AgRE Calc and The Cool Farm Tool both have a good data entry and reporting interface; and all three tools have positive aspects to the output data reporting. The comparison between tools leads to greater discrimination when the weaknesses are considered. All three tools have issues with the way carbon sequestration (e.g. carbon stock increase in woodland, or in soil under grassland) is accounted for, or not. This is unsurprising since there are large uncertainties in this aspect of carbon accounting. But, considering other weaknesses, The Cool Farm Tool stands out as having problems with the way forage crops are assessed, and having poor guidance available (although it is noted that improved guidance is in development and is expected to be available in 2019, and further testing for beef enterprises may lead to improvements). The threats for each of the tools relate to uncertainty about continuity or future support.

The main difference between tools is in the weaknesses, and in particular the weaknesses of The Cool Farm Tool that make it unsuitable at this time for multiple beef enterprise assessments in Scotland that can be used to scale up to a Scotland estimate.

Conclusions from the comparative analysis

This comparative analysis identified and compared 17 methods, of which three were shortlisted for more detailed comparison; these were AgRE Calc, The Cool Farm Tool, and Solagro CC. These were selected on the basis of the high-level comparison given in section 1.1.2. These three tools met the essential criteria based on the requirements to assess GHG emissions intensity for multiple beef farm enterprises in Scotland.

The outcome of the more detailed comparison was that two methods were taken forward for inclusion in the framework (see Appendix 1); these were AgRE Calc and Solagro CC. These were selected based on a test using a standard data set to compare functionality and user experience (1.1.2). The test was followed by a SWOT analysis (1.1.4), that used information from the test, and resulted in the selection of AgRE Calc and Solagro CC.

It is important to note that this conclusion relates to assessment of GHG emissions intensity for beef production, and the selection of tools may be different when other farming enterprises are considered. The Cool Farm Tool remains an important tool for assessment of farm GHG emissions and emissions intensity, and it is expected that it would have greater strengths and fewer weaknesses when used for crop production enterprises.

3. Availability of activity data and completed assessments

Introduction

When assessing greenhouse gas emissions from farming activities, there are key data requirements for the accurate assessment of emissions. National emissions inventories take a 'top down' approach to measurements that, put simply, multiply emissions factors by activity data. Emissions factors are standardised emissions associated with an activity e.g. annual methane emission from a suckler cow. The activity data is the number of occurrences of the activity such as the number of suckler cows or other livestock species. National inventories are a valuable source of information that are designed specifically to measure progress towards emissions reductions targets at a national level. The limitation of inventories is that they only consider absolute emissions and do not relate emissions to output. Emissions intensity is important to consider along with absolute emissions.

Emissions intensity is a measure of production efficiency, or emissions per unit of production. We have looked at data sources that could provide information relating to emissions intensity to determine an emissions intensity figure for beef production in Scotland.

Farm data is collected through several mechanisms annually. Survey data is collected relating to farm business incomes and financial performance through the farm business survey. The agricultural census gathers information on production. Much of this information is aggregated to a national scale so does not provide the granularity required to produce farm scale emissions calculations. There is some segmentation of data by enterprise and farm systems which provides some useful information but does not provide all the details required for an accurate measurement of emissions intensity.

Integrated Administration and Control System (IACS) data is collected annually from all farmers claiming from the basic payment system. It provides detailed information on crops and grassland areas and some information on livestock numbers. It can provide useful input data for GHG calculations but does not provide enough detail on farm management practices to produce GHG intensity values.

More recently, data specifically relating to GHG emissions intensity has become available through the increased usage of 'carbon calculator' tools. This has been accelerated through the Farm Advisory Service and Beef Efficiency Scheme in Scotland. The Carbon calculators we have reviewed process input data to provide GHG emissions per unit of output, measured as kg of carbon equivalent per kg of product.

Data sources reviewed

For this study, several data sources were assessed to determine their suitability in establishing a method for measuring GHG emissions intensity for Scottish beef production. These data fit in to two categories:

- Data from existing GHG emissions calculation tools (completed assessments). These tools collect information directly relating to GHG emissions intensity.
- Data that can be used as a proxy figures for GHG calculations (enterprise data): census and Farm business survey data.

1.1.5 Data from existing tools

The Cool Farm Tool, AgRE Calc and the Solagro tools were all assessed to determine their data capture functionality and the availability of those data. Solagro and Cool Farm Tool do not have the ability to share existing data. The Solagro tool is a standalone, Excel based tool and there is no data collection capability. The Cool Farm Tool does not collect and share data from users although it does have the functionality to do so if users wanted to. There are also concerns over suitability of the data outputs from the CFT for the purposes of measuring enterprise GHG intensity (detailed further in section 4). The AgRE Calc tool offered a good basis for data analysis as it has captured accessible data through the Scottish Government, Beef Efficiency Scheme (BES).

In addition, investigated the functionality of the Beef Carbon Navigator used in Ireland but this does not have the capability to deliver farm scale GHG intensity assessments.

The BES data source for farm-scale carbon footprint data, and GHG emissions intensity data is an excellent resource. All participants of the Scottish Government Scheme must undertake a 'carbon audit' as part of the scheme requirements. This has developed a data set of ~1,400 farms using AgRE Calc (see section 1.1.2). Data from 1,291 farms were available at the time of this project. An audit must be performed 3 times over the life of the 5-year scheme providing a time series as well as a good sample size.

1.1.6 Segmentation of BES Data

Segmentation of data helps to determine if there are specific characteristics of the enterprise type that effects the emissions intensity**.** The data were interrogated further to give an understanding of how segmentation into groups of producers could be done. The intention was to look at multiple criteria relating to production variables such as feed, forage, fertiliser, fertility and herd size as well as the production system (i.e. upland *vs* lowland and store *vs* finishing unit). However, we were unable to access the information on the production variables and production system as a direct download from AgRE Calc.

The solution was to manually extract data from AgRE Calc records for a sample of the available 1,291 records that would give us statistically robust estimates for GHG emissions intensity by segment. The manual extraction of over 100 records provided a usable sample of 92 samples from which each of four segments could be evaluated. In addition, AgRE Calc has a useful benchmarking function that allows for comparisons to be made against average data for similar enterprise types. This does not distinguish between finisher and store systems but does provide averages for upland and lowland systems. Data are presented in Table 2: the farms labelled "Upland finisher" and "Lowland finisher" were breeding and finishing beef cattle; the farms labelled "Upland store" and "Lowland store" were breeding and selling calves before finishing. The results of the analysis for store farms do not give a good indication of the carbon intensity of beef in Scotland because the emissions and production from the finishing phase (from sale to a finishing farm or sale for slaughter) are not included. The results of the analysis for finisher farms give a better indication of the carbon intensity of beef production in Scotland, based on the limited sample. Taking upland and lowland results together the data suggest a value of approximately 35 kg CO_2e per kg beef. This is an indicative value from the BES data set, and has not been subject to the scaling up methodology given in our framework (see Appendix 2, section 1.1.21), which includes checks for representation of the population of beef farms, and of sub-groups within this population.

Table 2. Summary statistics of the sample used.

Farm type	Sample size (no. of Farms)	Mean (kg CO_2e per kg beef)	AgRE Calc Benchmark
Upland finisher	20	38.83	40.83 Ave 564 reports
Upland store	26	52.68	
Lowland finisher	24	31.87	38.50 Ave 270 reports
Lowland store	22	38.19	

1.1.7 Farm Systems Data

Beef Production systems in Scotland are diverse and dependent on a range of geographic and climatic factors which influence the business decisions of individual farmers. Beef producers fit broadly in to three categories although there are many variations on these systems:

- Breeder/finisher: breeding cows (suckler cows) produce calves which are subsequently finished (ready for slaughter) on the same farm.
- Breeder/store: breeding cows produce calves which are subsequently sold on to another farmer to be finished.
- Finisher: purchases store cattle from a breeder to be finished.

The system type has an impact on the emissions intensity. When considering the intensity of beef as a finished product, the most representative of beef production systems is the breeder finisher group as this encompasses all the components of beef production and includes emissions from both breeding stock and the emissions from the finished animal. In effect, it considers the embedded emissions from the breeding stock. Generally, store cattle producers will tend to have a higher emissions intensity than finishers as they produce less output weight while incurring the emissions from all breeding stock. Specialist finishers have a significantly lower emissions intensity than the store animal producers as they do not carry breeding stock and have the associated emissions.

The structure of beef farms in Scotland are often restricted by geographical constraints, meaning there are farms able to produce store animals, but find it difficult to grow feed and forage to finish them, so animals are required to move to other farms to be finished. The movement of livestock tends to occur between upland farms producing store animals and lowland farms with straw for bedding and surplus grain suitable for animal feed. This relationship between farms realises the comparative advantage of store and finishing enterprises leading to greater efficiencies in production. However, it does present some challenges in assimilating the data to accurately assess the emission intensity when considering the activities of more than one farm. Therefore, recommendations have been made within this report to account for embedded emissions.

Obtaining the data to be able to reflect these complexities presents challenges. It is necessary to accurately account for emissions between breeder/store farms and finishing units, and at present, none of the GHG accounting tools assessed provide access to enough data to be able to reliably test the methodology presented. It would require full access to data on farming systems to be able to assess the full lifecycle emissions intensity. Following discussions with SAC consulting, we have established that these data could be extracted from the AgRE Calc, but some investment is required in the tool.

1.1.8 Proxy data for GHG emissions

To reduce the reliance on a single data source, we reviewed other possible data sources that could provide data on beef production systems in Scotland. This included farm survey data, such as from the Farm Business Survey.

The Farm Business Survey undertakes analysis of enterprises across Scotland including Enterprise Net Margin analysis for the beef sector[2]. This analysis is segmented by beef systems and provides financial data relating to costs of production. The segments are broken down as shown in Table 3.

[2] https://www2.gov.scot/Topics/Statistics/Browse/Agriculture-Fisheries/Publications/FASdata

Table 3: Beef production segmentation for enterprise net margin data.

Category	Description	Numbers in Sample 2016/17
Beef: Upland herds (weaning)	Less Favoured Area, Suckler cow herds with most (>75%) calves sold at ~6 months	11
Beef: Upland herds (yearlings)	Less Favoured Area, Suckler cow herds with most (>75%) calves sold at ~12 months	84
Beef: Upland Herds Forward Stores	Less Favoured Area, Suckler cow herds with most (>75%) calves sold store at ~18 months	29
Beef: Upland Herds Finished	Less Favoured Area, Suckler cow herds with most (>75%) calves finished	25
Beef: Lowland Herds (yearlings)	Non-LFA, Suckler cow herds with most (>75%) calves sold store at ~12 months	10
Beef: Lowland Herds Finished	Non-LFA, Suckler cow herds with most (>75%) calves sold finished	30

The Enterprise Net Margin data segments and sample size are detailed above, however, the level of granularity within the data was not detailed enough to allow the carbon calculator to be completed to provide an indicator for GHG intensity. For example, sale ages, fertiliser use, forage areas etc are not detailed. However, when used in combination with standard data from the Farm Management Handbook 2018/193, gaps could be filled and those outputs could be useful as a verification tool for the methodology. Although useful for verification purposes, It would not be appropriate to use this approach to develop the emissions intensity figure for Scotland as it does not account for the significant variability with individual farm businesses and does not reflect real farm data.

The data sources reviewed did provide a clear segmentation according to enterprise type. Although these categories do not account for the diversity of the intensity of the enterprises, other than between upland and lowland, and the point at which the animals are sold, they do provide a good basis for generalising emissions intensity according to production system that can be used in scaling.

This study reviewed the aggregated published data from the Farm Business Survey (FBS)4 to test the usefulness in determining GHG intensity from beef enterprises. While the published data does not provide the detail required to develop an accurate calculation, it is possible that reviewing the primary data may provide the required level of information. It would be useful to review the current data and collection templates to establish what, if anything would be required in addition to the existing data to provide the data required for an accurate GHG intensity calculation.

[3] Published by SAC and available vis the as part of the SRDP Farm Advisory Service, at: https://www.fas.scot/downloads/farm-management-handbook-2018-19/

[4] https://www2.gov.scot/Topics/Statistics/Browse/Agriculture-Fisheries/Publications/FASdata

4. A framework for benchmarking greenhouse gas emissions intensity in Scottish farming

Description and purpose

In order to calculate emissions intensity of agricultural products, we generated a framework that links to existing tools designed to capture GHG emissions at a farm or enterprise level. From this base, our framework applies statistical methods to enable the generation of a whole-Scotland estimate.

This framework provides a degree of standardisation in the calculations and assumptions used to estimate the GHG impact over a diverse array of beef farming systems.

Assessment boundaries are defined, including for time, territory, activities and materials, and GHGs to be included. Data requirements are also described for farm or enterprise assessments and for scaling up to a Scotland estimate.

Calculation methods are given by reference to other methods, tools, and publications, or are given directly.

The framework is given in full in Appendix 2 (section 7); here we provide a brief description of the framework.

Principles

This framework sets out some principles that will provide a level of consistency between assessments.

- Focus on GHG emissions – other environmental impacts are not addressed in this framework.
- Removals (sequestration of carbon from the atmosphere) may be included in the assessment of farm GHG (net) emissions, and if included, emissions of GHGs and removals of GHGs shall be reported as separate values.
- A 'cradle to gate' lifecycle approach – life cycle assessment (LCA) is a well-established technique that LCA approach to assess environmental impacts associated with the 'life' of a product. A full lifecycle covers all stage from raw material extraction (e.g. some fertilisers), production or manufacture of inputs (e.g. bought-in supplementary feed for livestock), delivery of raw materials, the production process, transport of the product, consumption, and disposal or recycling of any waste. A cradle to gate assessment covers part of this full lifecycle, from the beginning through to a defined end-point at which a production is complete, before further processing and consumption. In this framework the defined end-point is the farm gate, the point at which a live animal is taken away for slaughter.
- Recommended tools have similar approaches
- There are rules in the framework for assessment scope, assessment boundaries and data inputs.

Methods and tools employed for farm-level assessments

Approaches have been developed to calculate product carbon footprints, a measure of GHG emissions intensity. Some of these have general applicability to any goods or services, and some have been developed specifically for agricultural production. We have explored those relevant to agricultural production, to determine whether and how they could be used to estimate emissions intensity of beef production at a farm and at a national scale.

This framework draws on two existing tools for the assessment of GHG emissions intensity for an individual farm or enterprise. The two tools are listed in Appendix 3 (section 0) and were selected by the comparative analysis reported in Section 2. These tools are used to estimate GHG emissions, for farm enterprises, in this case, beef production. Outputs are estimates of GHG emissions intensity in units of kg CO2e/kg of product.

The two recommended tools include sequestration for some carbon sinks (e.g. farm woodland) but other possible sinks are not included (e.g. grassland management) because of high uncertainty. It is because of inconsistencies in the inclusion of carbon sinks that emissions of GHGs and removals of GHGs shall be reported as separate values. This improves the consistency of reported emissions values compared with net emissions (emissions minus removals) values.

Activity data requirements

The types of activity data needed by the two tools are shown in Appendix 2, section 1.1.18, Table 5. This is not an exhaustive list but is intended as a guide to help users prepare for an assessment, and to aid the selection of a tool by the user of the framework. The required activity data are broadly similar for the two tools, and include data on climate, land area, the herd, feed inputs and forage crops, manure management, inputs of manure, fertilisers, lime and pesticides, energy and water use, waste management, and transport.

Methods for scaling up from farm-level assessments to Scotland estimates

To assess the baseline GHG emissions intensity for beef production in Scotland, and to measure improvement at a Scotland level, it will be necessary to scale up from multiple farm-level estimates to Scotland-level estimates. A robust methodology for this scaling up is essential where the farm assessments are done for a sample of the total number of farms. The best data collection strategy would be to assess all farms, making the scaling-up methodology unnecessary, but it is recognised that, in practice, data are likely to be collected for a sample of farms.

Scaling up from multiple farm level assessments to a Scotland estimate requires confidence in the sampling strategy (the number of farms assessed and their selection). A method for achieving this confidence is given in Appendix 2, section 1.1.21. When a sample (data from a set of beef farms) has been obtained and there is confidence in the sampling strategy, the up-scaled result is the sample mean of the farm GHG emissions intensity assessments, in units of kg CO_2e per kg of production.

When upscaling to Scotland, care is needed for the correct representation of the whole production chain. The inclusion of store units (farms that breed calves and sell them on for finishing) will result in double counting because it is a feature of lifecycle assessment that emissions for the production of bought-in goods are included: therefore, the assessment of farms that buy stock from store units to finish them, will include the GHG emissions associated with the breeding phase on the store unit. So, for the upscaling exercise, only farms that finish (i.e. farms that sell stock for slaughter and use in the food industry) shall be included in the data set used to estimate a GHG emissions intensity for Scotland.

Strengths and weaknesses of the framework

A major strength of this framework is that it relies on existing tools that have been widely tested. In the case of AgRE Calc, there have been more than 1400 completed assessments with beef enterprises in Scotland, giving confidence in the practicality of its application.

There is an opportunity to expand the framework beyond application to beef production, to cover all sectors of agriculture in Scotland. This will require an extension of the comparative analysis to identify suitable tools that can be applied to other sectors of agriculture. The two tools selected for use in this framework, AgRE Calc and Solagro CC, are both suited for use across multiple types of enterprise, but alternative tools may also be added, such as The Cool Farm Tool for crop production, and other tools for specific systems such as salmon farming.

Weaknesses include the need for data collection across multiple farms, which takes time to organise and perform. The need to involve a suitably qualified statistician for upscaling may also be considered a weakness, but is an important element to ensure results that are robust.

The continued availability of tools is a threat. Some tools that were available a decade ago are no longer maintained. Resources are needed to maintain and continue the development of good carbon footprinting tools.

5. Conclusions and recommendations

Conclusions

This project has produced a methodology framework (Appendix 1) for assessment of GHG emissions intensity for beef farming in Scotland. The framework gives guidance for assessment of GHG emissions intensity at a farm or enterprise level, and for scaling up to obtain a Scotland estimate. Calculation methods are given by reference to other methods, tools, and publications, or are given directly.

The framework references two farm carbon footprinting tools, identified from a comparative analysis of 17 methods: AgRE Calc and Solagro CC. The Cool Farm Tool may be suitable for inclusion in the framework when some current development work is completed. Other methods and tools could be added to framework for application in other sectors of Scottish agriculture and horticulture.

The two tools referenced in the framework have been widely tested and this is a strength for the framework, giving confidence that it will produce the required outputs. For the beef sector in Scotland, one of the tools, AgRE Calc, has already been widely used as part of the Scottish Government's Beef Efficiency Scheme, providing a robust data source for beef production systems. Some challenges have been highlighted in relation to the extraction of the data from the AgRE Calc tool. Through the delivery of this project, there have been discussions with SAC consulting to establish if these challenges can be overcome. SAC have informed us that data downloads for all the necessary data will be possible. This also has positive implications for other enterprises in the future. When the full data set is available it will be possible to check for adequate representation of differing Scottish beef farming systems, and of regions. If gaps are evident at that stage, some more data collection may be needed.

Using additional data collection mechanisms to enhance the accuracy of the emissions calculation is possible. Information from detailed surveys of farms such as Enterprise Net Margin from the Farm Business Survey, could be used to verify data. It could also be possible to undertake a carbon audit during the process of collecting data from individual farms taking part in the survey as there are significant overlaps with the data required.

Implementation of the framework, and expansion to cover other food production sectors, will inform the decision-making process for delivery of the Scottish Government commitment to reduce the carbon footprint of the food we produce, by lowering the emissions associated with food production.

Recommendations

1. Implementation of this framework for the beef sector in Scotland, providing a full worked example to support work in other sectors

A full worked example would provide enhanced guidance for practitioners using the framework. This would also increase transparency for the beef sector analysis and provide policy makers with confidence to apply the framework to other sectors of Scottish agriculture. The implementation will require data on the total number of beef farms in Scotland, and how they break down into sub-groups, such as region, type of land (e.g. upland, lowland) and type of system (e.g. breeder finisher, breeder, finisher).

2. Expand the framework to cover all sectors of Scottish agriculture and horticulture

If the Scottish Government is to achieve its stated ambition to be among the 'lowest carbon', most efficient producers in the world, it must seek to measure and analyse GHG emissions intensity across all sectors of Scottish agriculture.

3. Analysis of beef data to draw out mitigation lessons

There is much that could be done with the large data set, from use of AgRE Calc in the Beef Efficiency Scheme, that is available for beef production in Scotland. This sector emits a large proportion of the GHG emissions from Scottish agriculture and therefore mitigation in this sector will play an important part in the effort to limit climate change. The data set contains much detail about management practices, production systems, location (and therefore land characteristics), etc., which would allow links to be made between these factors and GHG emissions intensity. This enhanced knowledge can help Scottish Government with policy development to facilitate improvement and decreased GHG emissions.

6. Appendix 1 – Project tasks

The project had three tasks which were done concurrently.

Task 1. Development of assessment framework

An assessment framework was developed, utilising existing farm carbon footprinting methods, assessment tools, and datasets.

First, we identified existing methods and tools that are suitable for application in Scottish farming, relevant to beef production and other sectors; this overlapped with Task 3 (the comparative analysis, see below). We then described a method for assessment at a farm scale, giving direction to suitable assessment tools and guidance for data collection, results presentation and interpretation of the outputs.

A method is also given for upscaling of assessments made at a farm scale to give an estimate for Scotland, taking account of sample size (i.e. the number of farms that have been assessed).

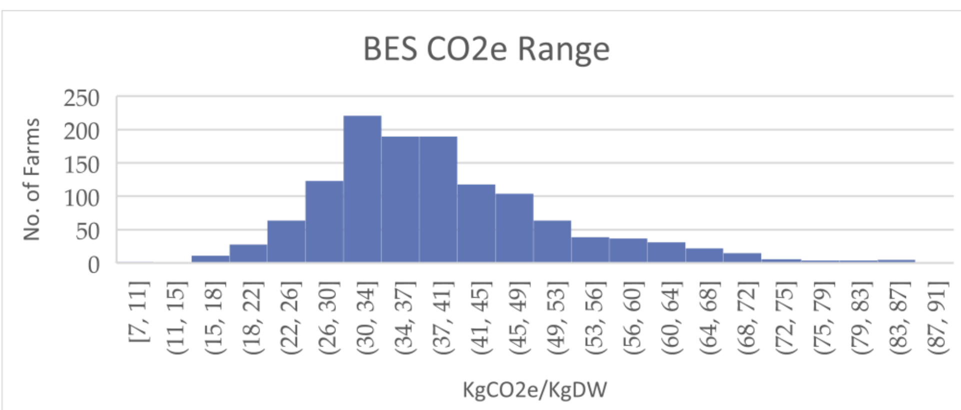
Task 2: Compile existing datasets

The availability of farm emissions data using tools that are used in the framework (section 0) was investigated and is reported in section 0. Scotland-level data sets were also investigated for potential to be used in the scaling-up of estimates from farm-level to Scotland-level, and to provide verification and increase confidence.

Anonymised data were extracted from the BES customer relationship management (CRM) system. This provided basic data relating to GHG intensity reported as kg CO_2e/kg beef output (carcass weight), and total farm emissions. The area of focus for us was the GHG emissions intensity data set.

Firstly, we assessed the distribution of emissions intensity for the total population of all BES participants (Figure 1). This shows a large range; the mean was 39.35 kg CO_2e/kg.

Figure 1: Distribution of emissions intensity for the total population of all BES participants



Task 3: Comparative analysis

Existing methods and tools were identified that are suitable for application in Scottish farming, relevant to beef production and other sectors. These were compared using criteria for acceptance or rejection, and a shortlist of methods and tools was taken forward for testing using a data set generated for the purpose. The results of the testing were compared together with the user-experience.

7. Appendix 2 – The Framework

A framework for benchmarking greenhouse gas emissions intensity in Scottish farming

Introduction and Background

Emissions of greenhouse gases (GHGs) from agriculture are particularly important in Scotland, with GHG inventories reporting 21% of emissions arising from agriculture in 2016[5], compared with a European Union (EU) average of ~11%[6]. Net removals of GHGs (sequestration) in the land use, land use change and forestry (LULUCF) assessment category in 2016, as percentages of total net emissions, were 23% for Scotland[3] and 7% for the EU[4]. Besides demonstrating the environmental importance of agriculture and land management in Scotland, this also reflects the economic importance of Scottish agriculture.

Inventories of GHGs focus on absolute emissions within defined geographic boundaries, but do not account for the production processes (e.g. of goods or services) that is associated with the emissions. The use of GHG emissions intensity as a measure for GHG emissions focusses attention on efficiency, or quantity of production per quantity of emissions. This allows comparison with emissions intensity of production by alternative methods, or in alternative locations. It also allows emissions to be related to consumption, and therefore can help to avoid unintended consequences such as emissions leakage when food is imported, and the production emissions occur outside the geographic boundary of the Scotland inventory.

Scottish Government has ambition to be among the 'lowest carbon', most efficient producers in the world. To provide evidence that this is the case, and measure improvement, a robust methodology for the measurement of GHG intensity is necessary. This is recognised in the Scottish Government's Climate Change Plan (The Third Report on Proposals and Policies 2018-2032, February 2018), which requires a "report into the establishment of emissions intensity figures for beef, lamb and milk".

An integrated approach to farming and land management is required to deliver the multiple policy priorities. Livestock, (beef cattle in particular) have an important role in sustainable farming systems which includes maintenance and enhancement of biodiversity, soil carbon sequestration in grassland and socio-economic benefits in rural Scotland. Scotland has significant diversity in its farming systems; this requires an approach that benchmarks GHG intensity for a variety of production systems, including intensive and extensive.

This framework provides a degree of standardisation in the calculations and assumptions used to estimate the GHG impact over a diverse array of beef farming systems.

Definitions of Key Terms

Activity data	Data on the magnitude of a human activity resulting in emissions or removals taking place during a given time period. Data on land areas, management systems, lime and fertilizer use, and waste arising are examples. (Adapted from 2006 IPCC Guidelines for National Greenhouse Gas Inventories, Glossary **G.3**)

[5] Greenhouse Gas Inventories for England, Scotland, Wales & Northern Ireland: 1990-2016 http://naei.beis.gov.uk/reports/reports?report_id=958

[6] European Environment Agency https://www.eea.europa.eu/data-and-maps/data/data-viewers/greenhouse-gases-viewer

Embedded emissions	Emissions of GHGs associated with the production of a raw material or other input to a production system
Emissions factor	A factor that converts activity data into GHG emissions data (e.g., kg CO2 e emitted per litre of fuel consumed, kg CO2 e emitted per kilometre travelled, etc.). (Adapted from GPC, p.163)
Emissions intensity	Mass (e.g. kg or tonne) of GHG (carbon dioxide equivalent, CO_2e) emitted per unit mass (e.g. kg or tonne) of output *NOTE: the value used for mass of GHG emitted shall be total (gross) emissions, not net emissions, i.e. before calculation of emissions intensity, removals must not be subtracted from emissions to give net emissions. This is because there is a lack of consistency in the scope of removals assessments.*
Primary activity data	Quantitative measurement of activity from a product's life cycle that, when multiplied by the appropriate emission factor, determines the GHG emissions arising from a process. (Adapted from PAS 2050:2011, 3.34)
Secondary activity data	Data obtained from sources other than direct measurement of the emissions from processes included in the life cycle of the product. Secondary data are used when primary data are not available, or it is impractical to obtain primary activity data. (Adapted from PAS 2050:2011, 3.41)

Overview for Applying this Framework

1.1.9 Concepts used in developing this framework

This framework uses tools and approaches that adhere to some common concepts and principles. These are:

Focus on GHG emissions

Other environmental impacts are not addressed in this framework.

A 'cradle to gate' lifecycle approach

Life cycle assessment is a well-established technique that LCA approach to assess environmental impacts associated with the 'life' of a product.

A full lifecycle covers all stage from raw material extraction (e.g. some fertilisers), production or manufacture of inputs (e.g. bought-in supplementary feed for livestock), delivery of raw materials, the production process, transport of the product, consumption, and disposal or recycling of any waste. A cradle to gate assessment covers part of this full lifecycle, from the beginning through to a defined end-point at which a production is complete, before further processing and consumption. In this framework the defined end-point is the farm gate, the point at which a live animal is taken away for slaughter.

Consistency between farm-scale assessments

A degree of consistency is achieved through use of tools with similar approaches and through provision of rules for assessment scope, assessment boundaries and data inputs.

1.1.10 Methods and tools employed for farm-level assessments

This framework directs the user to two existing and available tools for the assessment of GHG emissions intensity for an individual farm, or enterprise within a farm. The two tools are listed in Table 4, and were selected by the comparative analysis reported in Section 2. These tools are used to calculate GHG emissions, for a farm enterprise, in this case, beef production.

Table 4: Assessment tools for GHG emissions intensity, selected for use in this framework.

Name of tool	Responsible organisation	Web address	Software type
AgRE Calc	SAC Consulting	http://www.agrecalc.com/	Web application
Solagro CC	Solagro	https://solagro.org/nos-domaines-d-intervention/agroecologie/carbon-calculator	Microsoft Excel

The Agricultural Resource Efficiency Calculator (AgRE Calc) was developed by SAC Consulting and is aligned with PAS2050 and uses IPCC Tier I and Tier II calculations. AgRE Calc can be used to assess farm GHG emissions for a whole farm, by enterprise (multiple enterprises per farm), and as GHG emissions intensity (i.e. per unit of output). Enterprises that can be assessed include:

- Beef
- Sheep
- Dairy
- Pigs
- Poultry
- Cereals
- Oilseeds
- Potatoes
- Vegetables
- Fruits

AgRE Calc has been tested for beef through its use in the Scotland Beef Efficiency Scheme to assess approximately 1400 beef enterprises.

Assessment results are expressed as total emissions (CO_2e) and emissions per kg of production (emissions intensity). Practical measures to improve efficiency and reduce emissions are suggested

The Solagro Carbon Calculator (also known as the Carbon Calculator and abbreviated in this report to Solagro CC) was developed by Solagro for the European Commission's Joint Research Centre (JRC). Solagro CC was designed to assess the life cycle GHG emissions from farming systems across the whole EU.

In addition to the GHG emission quantification, the tool proposes mitigation and sequestration actions. Farming practices are recommended for potential emission reduction, avoidance of leakage effects, effects on other environmental impact categories, and costs.

The Solagro CC has been tested on a wide diversity of farm types across all major environmental zones in the EU.

Solagro CC reports GHG emissions as total emissions per functional unit: per ha of Utilised Agricultural Area, per tonne of milk, per tonne of live weight meat, per tonne of dry matter, and per tonne of fresh matter.

1.1.11 Methods for scaling up from farm-level assessments to Scotland estimates

Scaling up from multiple farm level assessments to a Scotland estimate requires confidence in the sampling strategy (the number of farms assessed and their selection). There are five main elements to the method for achieving this confidence:

A. Obtain the minimum viable sample size using a statistical approach.
B. Ensure that the sample distribution properly represents the population distribution.
C. Obtain the sample.
D. Test for appropriate sample size by re-calculating sample sizes for sub-groups that are of interest, followed by further sampling if needed to ensure an adequate sample within each sub-group.
E. If insufficient data are available on important variables for analysis (such as farm type), statistical methods (classification or clustering) can be used to find a set of categories in the data.

When the sampling is complete, the up-scaled result is the sample mean GHG emissions intensity in units of kg CO_2e per kg of production.

Defining the GHG Assessment Boundaries

1.1.12 Temporal boundary

The assessment shall include all relevant activities during one calendar year.

1.1.13 Territorial

The assessments at farm scale shall include the land and buildings used in the enterprise of interest (in this case, land and buildings used for beef production).

The farm may have other enterprises (e.g. horticultural or arable) that use land within the farm for other purposes: this land shall not be included.

Where land is used to produce raw materials for input to the beef system, an assessment shall be done for that activity to provide input data for the assessment of the beef production system.

1.1.14 Activities and materials

Activities and materials shall be included for the whole life cycle except parts of the lifecycle beyond the farm gate. The farm gate is defined as the point at which a live animal is taken away for slaughter. Therefore, the following parts of the lifecycle shall be excluded: transport from the farm, slaughter, carcass preparation, further processing and packaging, further transport, retail, consumption, waste processing.

The cradle to farm gate lifecycle shall include emissions from the production of inputs not produced on the farm, such as manufactured fertilisers, and calves bought from another farm.

1.1.15 Greenhouse gases

The following GHGs shall be included:

- Carbon dioxide (CO_2), excluding CO_2 emitted from biogenic carbon sources;
- Methane (CH_4);
- Nitrous oxide (N_2O);

The following GHGs may be included:

- Hydrofluorocarbons (HFCs);
- Perfluorocarbons (PFCs);
- Sulphur hexafluoride (SF_6);

- Nitrogen trifluoride (NF_3).

In practice, most GHG emissions from agriculture are CO_2, CH_4 and N_2O; emissions of the other gases listed above will be immaterial in most assessments.

The focus of the framework is on GHG emissions. Removals (sequestration of carbon from the atmosphere) may also be included in the assessment of farm GHG (net) emissions (see 1.1.17).

1.1.16 Offset mechanisms

Offset mechanisms shall be excluded.

1.1.17 Sequestration (removals)

Sequestration of carbon (removal of carbon from the atmosphere) may be included in the assessment of farm GHG (net) emissions. The tools available at present include sequestration for some carbon sinks (e.g. farm woodland) but other possible sinks are not included because of high uncertainty.

If removals are included, emissions of GHGs and removals of GHGs shall be reported as separate values (see section 0).

Matching Systems and Segments to Appropriate Methodologies

Both of the two tools identified in this framework are suitable for assessment of GHG emissions intensity of beef production systems.

When this framework is expanded for application to other enterprises (e.g. dairy, arable, horticulture), additional tools may be included, and information will be provided to match tools to farming systems.

Data Requirements and Selection

1.1.18 Farm assessment

Emission factors are included within the tools, so users will not need to supply these.

The user of an assessment tool will need to supply activity data. The main types of data needed are shown in Table 5. This is not an exhaustive list but is intended as a guide to help users prepare for an assessment, and to aid the selection of a tool.

The best data collection strategy would be to assess a complete sample of all relevant farms, making the scaling-up methodology (section 1.1.19) unnecessary, but it is recognised that, in practice, data are likely to be collected for a sample that is a subset of the population of relevant farms.

Table 5: The main types of activity data needed for each tool.

Activity	AgRE Calc	Solagro CC
Climate	Annual average temperature (°C)	Detailed information on temperature and rainfall Climatic zone

Activity	AgRE Calc	Solagro CC
Farm and Land	Areas (1) owned and tenanted, (2) seasonal (ha) Annual occupancy of seasonal land (%) Woodland type (conifer or broadleaved), approximate age and area (ha) Area of buildings, yards, roads (ha)	Location Area of farm (ha) Annual Work Units (number of people employed on the farm, full-time equivalents) The main farm products (up to five) Dominant soil type, texture, pH Areas (widths and lengths, m) of woodland, hedges, orchards, wetland etc.) Area of land use change in last 20 years (e.g. grassland to cropland, ha) Buildings: age, area (m^2) and materials (optional)
Herd details	Numbers of types of cattle (e.g. suckler cows, heifers) with ages for heifers and steers in one-year intervals Average liveweights by type (kg) By animal type, purchases, sales (number and average liveweight, kg) and numbers of deaths Calving (%) Average daily live weight gain (kg/head/d)	Numbers of types of cattle (e.g. suckler cows, heifers) with ages for heifers and bullocks; this for the beginning and end of the one-year assessment period, and for animals sold and purchased
Feed inputs	Purchased feed (t) by type	Forage intake (t dry matter per year), home produced and purchased, by type, with digestibility values (DE%) Feed intake (t fresh matter per year), home produced and purchased, by type, including simple feed (e.g. grain) and composed or mixed feeds
Manure management system, bedding	Time (%) in different systems (e.g. grazing, deep bedding) Purchased bedding (t) by type	Quantity of manure (% of annual manure dry matter) managed in different systems (e.g. solid storage, slurry)

Activity	AgRE Calc	Solagro CC
Crops	Type of forage Combinable crop types if used from the same farm Crop areas (ha) Percentage of crop removed at grazing or harvest Dry matter at harvest (%) Yield (t/ha) Use (sold, fed, bedding) (t) Allocation of crops to different livestock types (e.g. beef, sheep) (%)	Crop areas (ha) Yield (t/ha) Use for other farm products (e.g. animal feed) or "other" (%) Grassland management (e.g. is it overgrazed?)
Fertiliser inputs	Urea (t) applied by crop type Fertiliser products applied (t) by crop/woodland type, with content of N, P, K (%)	Fertiliser purchases (t/year) by product For each crop: • fertiliser components applied (kg/ha) by fertiliser product • organic manure applied (m3/ha) by type, and with application method • crop residue management
Imported manure and lime	For manures: • quantities applied (t or m^3) by crop/woodland type • N and P content (kg/t or m^3) For lime: quantity applied (t) by crop/woodland type	(Imported manure and lime is covered under fertiliser inputs) Imports and exports of organic matter (optional)
Pesticide inputs	For combinable crops only, areas treated (ha) by pesticide type (herbicides, insecticides, fungicides)	For each crop: number of treatments by pesticide type (herbicides, insecticides, fungicides)

Activity	AgRE Calc	Solagro CC
Electricity and fuel	Quantities (kg) by type (e.g. electricity, kWh; red diesel, L), EITHER for the whole farm OR by enterprise	Number of machinery operations by type, with fuel consumption for each Use of fuels for machinery and vehicles, divided between crops and animal buildings Use of electricity (kWh) divided between irrigation and other
Waste	Quantities (kg), EITHER for the whole farm OR by enterprise	Fate of other inputs such as bags and string
Transport	Distances (km) for external haulage, EITHER for the whole farm OR by enterprise	Type of vehicle, age, use by the farm (%) [for owned vehicles, fuel use is covered under fuels]
Water	Quantities (L), EITHER for the whole farm OR by enterprise	Details of irrigated area (ha), water applied (m^3/year), type of energy used
Other		Quantities of other inputs (e.g. bags, string, plastic mulch, kg) by farm product Farm machinery details: type, age, annual use (h), divided between farm products (%) Refrigerants used in buildings and equipment: cooling capacity (kW) and type of fluid

Because beef production from breeding of calves through to slaughter for meat does not always occur on a single farm and some calves are bred for finishing at other farms, an estimate of emissions intensity needs to take account of this movement between farms. However, the two carbon footprinting tools do not include embedded emissions in livestock bought from another farm.

This is a challenge for any farm that buys calves for finishing. The challenge can be overcome by additional data collection. The best solution is for the assessment to use data from the farm supplying calves for finishing. To obtain the required data the practitioner can work with the farm supplying calves and use the chosen carbon footprinting tool to make an estimate of the emissions from producing the calves. These emissions can then be added into the estimate of total emissions for the finishing farm, either within the tool, as an additional input, or by adding the emissions after the assessment with the tool, and manually revising the estimate of emissions intensity (emissions divided by production).

1.1.19 Scaling up

Data requirements for scaling up are the output data from farm assessments, with a sufficient number of farms assessed to provide mean farm-level estimate that is representative of the beef production industry in Scotland. Further sections of this framework provide guidance to determine whether or not the sample size (number of farms assessed) is sufficient.

Calculation of GHG Emissions Intensity

1.1.20 Farm assessment

Calculations are done for the user within the selected tool. Any emissions not assessed by the chosen tool (e.g. embedded emissions in livestock bought from another farm), but required for a cradle to gate assessment, shall be added to the emissions total, and used to revise the estimate of emissions intensity given by the tool.

1.1.21 Scaling up

When upscaling to Scotland care is needed about the correct representation of the whole production chain. The inclusion of store units (farms that breed calves and sell them on for finishing) will result in double counting because it is a feature of lifecycle assessment that emissions for the production of bought-in goods are included: therefore, the assessment of farms that buy stock from store units to finish them, will include the GHG emissions associated with the breeding phase on the store unit. Therefore, for the upscaling exercise, only farms that finish (i.e. farms that sell stock for slaughter and use in the food industry) shall be included in the data set used to estimate a GHG emissions intensity for Scotland.

Scaling up from multiple farm level assessments to a Scotland estimate requires confidence in the sample size (the number of farms assessed) and the sampling strategy (the way of selecting the sample). To gain this confidence, knowledge of (or an estimate of) the population size and distribution is needed (the number of farms within the sector of interest in Scotland). If lacking such knowledge, the sampling strategy should be meticulous to achieve confidence that any selected sample is representative of the population. The following are the main elements to the method for achieving this confidence for a given sector.

A. To obtain the minimum viable sample size, a statistical approach is proposed to determine the minimum sample size, where the population and the sample are expressed as numbers of farms.
B. To ensure that the sample distribution properly represents the population distribution, a qualitative analysis of the sampling strategy is carried out before sampling takes place. It is important that the sampling strategy will ensure that the sample distribution matches the population distribution A qualitative analysis of the sampling strategy will ensure there is no impactful bias in a relevant parameter, and that all important clusters of farms with unique characteristics are sampled.
C. Obtain the sample, ensuring that information and additional data points are gathered about sub-groups of the sample (e.g. farm size, farm type, or sub-sector).
D. To test for appropriate sample size, re-calculate of sample sizes for sub-groups that are of interest, followed by further sampling if needed to ensure an adequate sample within each sub-group.
E. If insufficient data are available on important variables for analysis (such as farm type), statistical methods (classification or clustering) can be used to find a set of categories in the data.

When confidence in the sample size is achieved, then the sample mean value(s) of GHG emissions intensity (for the sector and for sub-sectors) provide an estimate for Scotland.

The method is given in more detail below in numbered steps.

A: To obtain minimum viable sample size:

1. Estimate the population size.
   This may be available from the Agricultural Census Branch, of The Scottish Government Rural and

Environment Science and Analysis Division. Some data are available online, such as "Agriculture Facts and Figures[7]" and this provides numbers of holdings in the following categories:

- Cereal
- General cropping
- Horticulture
- Pigs
- Poultry
- Dairy
- Sheep & Cattle LFA
- Sheep & Cattle non-LFA
- Mixed
- Forage
- Other

2. Determine the initial sample size using needed to estimate the population mean with known confidence and with known margin of error (precision).

A competent statistician should be engaged to determine the initial sample size. There is much guidance available on the internet and some examples are given here:
https://www.isixsigma.com/tools-templates/sampling-data/how-determine-sample-size-determining-sample-size/
https://newonlinecourses.science.psu.edu/stat500/node/35/
http://www.r-tutor.com/elementary-statistics/interval-estimation/sampling-size-population-mean
Online calculators are also available, but should be checked before use by a competent statistician.

A confidence level must be chosen and 95% is suggested, which will give 95% confidence that the sample mean will be within the margin of error.

A margin of error must be chosen. For example, a value of 5% of the expected mean could be used, with the expected mean being based on other published studies. For example, if previous studies suggest a GHG emissions intensity value of 40 kg CO_2e/kg for beef in Scotland, 5% margin of error is 2 kg CO_2e/kg.

$$n = \left(\frac{z_{\alpha/2} \cdot \sigma}{E}\right)^2$$

where:
n is the required sample size
α is 1 minus the confidence level expressed as a proportion (α=0.05 for 95% confidence)
Z is the Z-score (z=1.96 for α=0.05)
σ is the standard deviation of the population mean
E is the margin of error

σ is not usually known, so must be estimated from sample data or guessed, with correction after some sample data is available. Σ may be calculated as the product of s and √n, where s is the standard error.

If the population size is known then a finite population correction (FPC) factor may be applied: correction factor may be applied:

[7] https://www.gov.scot/binaries/content/documents/govscot/publications/statistics-publication/2018/06/agriculture-facts-figures-2018/documents/00536433-pdf/00536433-pdf/govscot%3Adocument (Accessed 15 February 2019)

$FPC=((N-n)/(N-1))^{0.5}$

where:
N is the population size
n is the sample size

If the population size is known to be small, and the determined sample size is small then it is recommended that a minimum sample size of 30 is implemented to provide enough degrees of freedom for subsequent statistical tests.

B: To ensure that the sample distribution properly represents the population distribution:

1. Correct for any potential bias from the sampling method (e.g. bias because of sample self-selection), follow the method given by Emerson and MacFarlane (1995).
2. Check that no important clusters of farms are excluded, using dimensions such as geographical location, size and type. This requires a qualitative check on the farming sector of interest, including geographic spread, farm size spread, etc.
3. Decide on a sampling strategy based on random selection, within strata (e.g. by farm size, production system, geographic area).

C: To obtain the sample:

1. Deploy sampling strategy. A sample may already be available in the form of a data set previously collected through farm-level or enterprise-level assessments of GHG emissions intensity.
2. When an important variable is not available, search for alternative variables that could represent the same thing (e.g., if lowland or upland is not available, obtain postcode data to determine geography). Build in redundant variables like these in any questionnaire for important variables.

D: To test for appropriate sample size,

1. Produce distributions and test for normality. Divide into sub-groups and re-check for each sub-group. If the full sample distribution is not normal, testing distributions for each sub-group can identify which group is causing the deviation.
2. Decide on sub-groups based on previous step and also sub-groups of interest, e.g. farm size, production systems. Also decide on stratification of the sector. Finalise the selection of sub-groups based on the previous step. Calculate sample sizes for each sub-group (see step A 2 above).
3. Use Analysis of Variance (ANOVA) to test for significance of differences, e.g. effect of farm size or type, and use Levene's test for normality to assess equality of variances between groups.
4. Obtain more assessments if required so that the sample sizes for each sub-group are adequate. To test the appropriateness of the sample size, the power of the binary hypothesis test in the ANOVA analysis is determined. This is why it is important to test for normality, as the tests for power assume equal variances among groups (e.g. farm type). When variances are not equal, it is recommended to remove outliers from the dataset until variances are equal. Power analysis can be done using various online tools, such as GPower[8]. A power of 0.8 or above is generally considered adequate.

E: If insufficient data are available on what groups exist in the sample for analysis:

1. Use statistical classification methods[9] to obtain information on sub-groups, such as cluster analysis (unsupervised learning, whereby groups are identified within the data by an algorithm) or classification

[8] https://stats.idre.ucla.edu/other/gpower/one-way-anova-power-analysis/
[9] For an example see: https://www.researchgate.net/publication/262525582_Cluster_Analysis_for_Classification_of_Farm_Households_Based_

methods (supervised learning, manually classifying some farms, and using this information to classify the rest).

When the sampling is complete, the up-scaled result is the sample mean GHG emissions intensity in units of kg CO_2e per kg of production.

Reporting

Results of farm-scale assessments shall be presented in units of kg CO_2e per kg of production, where kg of production is kg of liveweight of animals ready to leave the farm for slaughter. Input activity data shall be made available with the results.

Results for Scotland, scaled up from farm-scale assessments, shall be presented in units of kg CO_2e per kg of production, where kg of production is kg of liveweight of animals ready to leave the farm for slaughter. Supplementary data shall be provided for the population of farms in Scotland, and the sample size (number of farms assessed).

Emissions of GHGs and removals of GHGs shall be reported as separate values.

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8. Appendix 3 – Details of assessment tools and methods

Methods and tools identified

Table 6: List of methods identified, web addresses and brief description

Method	Short name	Web address	Description/notes
Agricultural Resource Efficiency Calculator (AgRe Calc)	AgRE Calc	http://www.agrecalc.com/	Software tool using a web application (PHP), life cycle approach, results can be provided per unit output, PAS 2050 aligned
AHDB Environmental and Agricultural Resource Efficiency Tool (EAgRET)	EAgRET	https://cereals.ahdb.org.uk/publications/2016/april/11/ahdb-environmental-and-agricultural-resource-efficiency-tool-(eagret).aspx	Not publicly available
AHDB LAMB 'WHAT IF?' TOOL	AHDB Lamb	http://www.alltech-e-co2.com/ahdb-lamb-what-if-tool/	For lamb only
ALLTECH DAIRY 'WHAT IF?' TOOL	Alltech Dairy	http://www.alltech-e-co2.com/alltech-dairy-tool/	For dairy only
ALLTECH E-CO2 BEEF 'WHAT IF?' TOOL	Alltech Beef	http://www.alltech-e-co2.com/beef-tool/	For beef, but not publicly available
CALM tool	CALM tool	https://ec.europa.eu/eip/agriculture/en/find-connect/projects/calm-%E2%80%93-useful-online-carbon-calculator-land	Not publicly available, apparently not maintained
Carbon Navigator	C Navigator	https://www.teagasc.ie/about/our-organisation/connected/online-tools/carbon-navigator/	This tool is widely used in Ireland, but does not provide a carbon footprint value as standard output
CFF Farm Carbon Calculator	CFF FCC	https://www.cffcarboncalculator.org.uk/	Does not provide a carbon intensity value (emissions per unit of production)

Method	Short name	Web address	Description/notes
Cool Farm Tool	CFT	https://coolfarmtool.org/coolfarmtool/greenhouse-gases/	International, web application interface, life cycle approach, results can be provided per unit output,
CPLAN	CPLAN	Not found	Apparently not maintained
Fieldprint Platform	Fieldprint	https://fieldtomarket.org/our-program/fieldprint-platform/	USA, Field to Market's Supply Chain Sustainability Program; for crops only
GHG Protocol Product Standard	GHG Protocol	http://ghgprotocol.org/product-standard	LCA principles, a recognised, written method but not a tool
LCA plus database	LCA	Not applicable	An approach using bespoke spreadsheet and commercial database input data for emission factors (e.g. (SimaPro, Ecoinvent)
PAS 2050	PAS 2050	https://shop.bsigroup.com/forms/PASs/PAS-2050/	Consensus-based written method, widely tested, LCA principles, but not a tool
PAS 2050-1	PAS 2050-1	https://shop.bsigroup.com/Browse-By-Subject/Environmental-Management-and-Sustainability/PAS-2050/PAS-2050-1/	Assessment of life cycle greenhouse gas emissions from horticultural products
PAS 2050-2	PAS 2050-2	https://shop.bsigroup.com/Browse-By-Subject/Environmental-Management-and-Sustainability/PAS-2050/PAS-2050-2/	Assessment of life cycle greenhouse gas emissions - Supplementary requirements for the application of PAS 2050:2011 to seafood and other aquatic food products
Solagro Carbon Calculator	Solagro CC	https://solagro.com/focus-areas/agroecology/carbon-calculator	Life cycle approach, results can be provided per unit output, Microsoft Excel interface

Tools shortlisted for detailed assessment

The Agricultural Resource Efficiency Calculator (AgRE Calc) was developed by SAC Consulting and is aligned with PAS2050 and uses IPCC Tier I and Tier II calculations. AgRE Calc can be used to assess farm GHG emissions for a whole farm, by enterprise (multiple enterprises per farm), and as GHG emissions intensity (i.e. per unit of output). Enterprises that can be assessed include:

- Beef
- Sheep
- Dairy
- Pigs
- Poultry
- Cereals
- Oilseeds
- Potatoes
- Vegetables
- Fruits

AgRE Calc has been tested for beef through its use in the Scotland Beef Efficiency Scheme to assess approximately 1400 beef enterprises.

Assessment results are expressed as total emissions (CO_2e) and emissions per kg of production (emissions intensity). Practical measures to improve efficiency and reduce emissions are suggested

The Cool Farm Tool (CFT) is maintained by The Cool Farm Alliance (CFA) and is based on published data sets and IPCC methods. It can be used for most farming systems, including crop and livestock systems, but has been tested only for beef systems in this project.

The Cool Farm Tool is free to use for farmers, but requires membership for multiple assessments. It has been tested by members of The Cool Farm Alliance (including large food companies) who have used the CFT within supply chain efficiency programmes. The user Guide on the CFA website is for assessment of crop systems only and use of the CFT for livestock systems is less-well tested than for crops. Further documentation for livestock systems is in preparation.

The Solagro Carbon Calculator (also known as the Carbon Calculator and abbreviated in this report to Solagro CC) was developed by Solagro for the European Commission's Joint Research Centre (JRC). Solagro CC was designed to assess the life cycle GHG emissions from farming systems across the whole EU.

In addition to the GHG emission quantification, the tool proposes mitigation and sequestration actions. Farming practices are recommended for potential emission reduction, avoidance of leakage effects, effects on other environmental impact categories, and costs.

The Solagro CC has been tested on a wide diversity of farm types across all major environmental zones in the EU.

Solagro CC reports GHG emissions as total emissions per functional unit: per ha of Utilized Agricultural Area, per tonne of milk, per tonne of live weight meat, per tonne of dry matter, and per tonne of fresh matter.

9. Appendix 4 – Evaluation of carbon footprinting methods against essential criteria

The identified methods were evaluated against a list of essential criteria, which given in the header row of Table 7. The simple criteria were in the form of questions that that could be answered yes or no and were based on the requirements to assess GHG emissions intensity for multiple beef farm enterprises in Scotland, from cradle to gate, i.e. the lifecycle including raw materials for production through the production on farm, as far as the farm gate where a product is ready for sale.

Table 7: results of evaluation of carbon footprinting methods against essential criteria

Method	The tool and adequate documentation available?	The tool is applicable to the beef sector?	Activity data is available or can be collected?	Emission factors provided, or available?	Lifecycle approach?	Useable by a farm advisor in a reasonable time?	Suitable for cradle to farm gate assessment?	Carbon footprint per unit of production?	All major sources of emissions are included?
AgRe Calc	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
EAgRET	No								
AHDB Lamb	?	No							
Alltech Dairy	?	No							
Alltech Beef	No								
CALM tool	No								
C Navigator	Yes	Yes	Yes	Yes	Yes	Yes	Yes	No	
CFF FCC	Yes	Yes	Yes	Yes	Yes	Yes	Yes	No	
CFT	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
CPLAN	No								
Fieldprint	Yes	No							
GHG Protocol	Yes	Yes	Yes	Yes	Yes	No			
LCA	Yes	Yes	Yes	Yes	Yes	No			
PAS 2050	Yes	Yes	Yes	Yes	Yes	No			
PAS 2050-1	Yes	No							
PAS 2050-2	Yes	No							
Solagro CC	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes

10. Appendix 5 – Testing of tools – user experience

Testing of the tools for the purposes of comparing functionality and user experience was undertaken using a standard set of notional farm data developed using results from previous work with the beef sector in Scotland. The purpose was to test the usability of the tools. Some tabulated information on the user experience with each of the three tools is given below in Table 8, Table 9, and Table 10.

Table 8: AgRE Calc test results – user experience

Attribute	Notes
User interface	The web-based platform steers the user through a series of logical data entry tables. Farm details and enterprise details are entered first before more detailed data entry. The following menu structure is used for data entry: • Land and Crops • Land/crop areas • Fertiliser • Manure and Lime • Pesticides • Crop production • Crop use allocated to livestock • Livestock • Numbers and weights • Sales, purchases, deaths • Performance • Manure management • Bedding • Feed (multiple tabs) • Energy and Waste • Electricity and Fuel • Renewable electricity • Renewable heat • Transport, Waste and Water The interface is in a simple, tabular format.
Complexity for users	Overall the data requested should be obtainable by a farmer with a reasonable approach to record keeping and basic knowledge of their farming system. However, there are areas that may cause some farmers difficulties, including: • Reconciling fuel and energy usage against enterprise activities. The tool has incorporated an automated allocation to enterprise based on standard values which is useful is and likely to improve the consistency of assessments compared with farmer-estimated allocation. • Grassland crop removals by grazing might be difficult for some farmers to estimate unless they are measuring swards regularly. There are some typical values used within the guidance document, but it would be better to have these values within the tool as default values.
Data Entry	Units are clear although some farmers might prefer to see options for land area in both acres and hectares. This is a minor point and generally the data input is requested in an intuitive way.

Attribute	Notes
Gaps in emission or removal sources	Key gaps relate to sequestration potential. It is unclear from the guidance what is included in sequestration estimates, but it appears only to be the sequestration from Farm woodland[10]. AgRE Calc does not include sequestration from other woody biomass such as hedgerows. It also does not include any estimates for grassland sequestration, but we understand that this is under development.[11]
Reporting	There are many useful functions of the AgRE Calc reporting. Firstly, it offers measures of GHG in multiple ways which importantly include a GHG intensity value in kg CO_2e/kg of output, offering both a liveweight and deadweight option. It also includes whole farm or enterprise emissions. The reporting structure gives an option to view comparative data which provides benchmarking opportunities. There are other outputs provided such as environmental indicators for water, nitrogen, phosphate and potassium use, although these indicators are not contextualised to show whether they are high, medium or low. The addition of financial data is useful to monetise efficiencies that have an impact on GHG emissions.

Table 9: Cool Farm Tool test results – user experience

Attribute	Notes
User interface	The interface is easy to use. The visual appearance of the user interface is good but the need to separate out forage crops into a separate analysis causes confusion. The data input format is completed through a series of input data tabs. The Beef enterprise data input tabs are as follows: • General • Production • Herd • Grazing • Feed • Manure • Energy • Transport The crop input for silage production is done through a separate assessment under the following headings: • Crop • Soil • Inputs • Fuel and Energy • Irrigation • Carbon • Transport

[10] Based on discussions with SAC Consulting.
[11] Uncertainty for grassland sequestration is high.

<table>
<tr><th>Attribute</th><th>Notes</th></tr>
<tr><td>Complexity for users</td><td>The main area of complexity relates to the separation of enterprise types. For our notional farm, which is a simple beef enterprise, we needed to separate out the forage crops and beef production system. This creates problems for determining enterprise emissions as there are separate outputs for the same beef enterprise in our case. Although there is a tab labelled “aggregation”, this does not appear to be functioning at present.</td></tr>
<tr><td>Data Entry</td><td>The format is relatively clear although some of the units and terminology are designed for an international market and might not be immediately clear to Scottish farmers.</td></tr>
<tr><td>Gaps in emission or removal sources</td><td>It is unclear how or where sequestration opportunities are recorded and calculated.</td></tr>
<tr><td>Reporting</td><td>The reporting structure is clear although the separation of forage from the beef enterprise make understanding the overall emissions difficult.

The report provides:
• Emissions per unit liveweight (kg CO_2e/kg)
• Total Farm emissions (kg CO_2e)
• A breakdown of GHG by source and gas

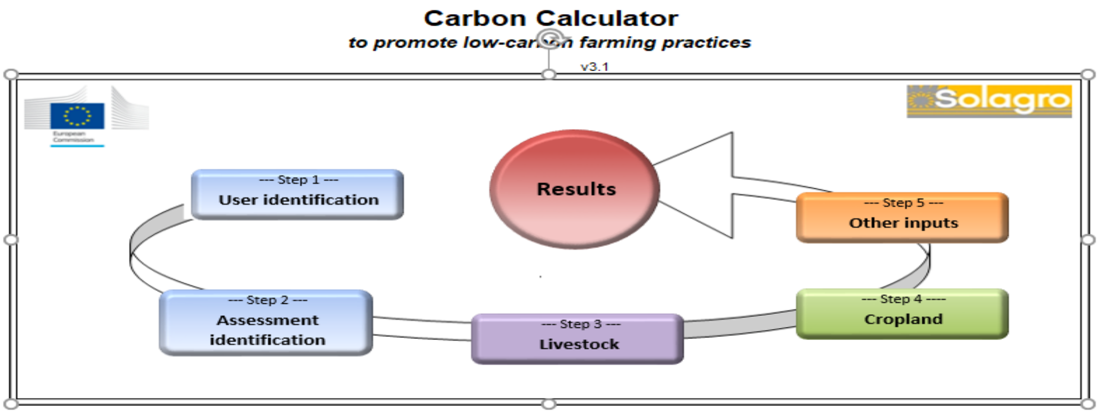
Example output:

Detailed data (all values in kg)
<table>
<tr><th>Sources</th><th>CO_2</th><th>N_2O</th><th>CH_4</th><th>Total CO_2 eq</th><th>Per ha</th><th>Per tonne</th></tr>
<tr><td>Seed production</td><td>0</td><td>0</td><td>0</td><td>0</td><td>0</td><td>0</td></tr>
<tr><td>Residue management</td><td>0</td><td>10.39</td><td>0</td><td>3.10k</td><td>143.30</td><td>7.16</td></tr>
<tr><td>Fertiliser production*</td><td>11.11k</td><td>0</td><td>0</td><td>11.11k</td><td>514.26</td><td>25.71</td></tr>
<tr><td>Soil / fertiliser</td><td>0</td><td>22.33</td><td>0</td><td>6.65k</td><td>308.04</td><td>15.40</td></tr>
<tr><td>Paddy methane</td><td>0</td><td>0</td><td>0</td><td>0</td><td>0</td><td>0</td></tr>
<tr><td>Crop protection</td><td>0</td><td>0</td><td>0</td><td>0</td><td>0</td><td>0</td></tr>
<tr><td>Carbon stock changes</td><td>0</td><td>0</td><td>0</td><td>0</td><td>0</td><td>0</td></tr>
<tr><td>Energy use (field)</td><td>6.12k</td><td>0</td><td>0</td><td>6.12k</td><td>283.26</td><td>14.16</td></tr>
<tr><td>Energy use (processing)</td><td>0</td><td>0</td><td>0</td><td>0</td><td>0</td><td>0</td></tr>
<tr><td>Waste water</td><td>0</td><td>0</td><td>0</td><td>0</td><td>0</td><td>0</td></tr>
<tr><td>Off-farm transport</td><td>0</td><td>0</td><td>0</td><td>0</td><td>0</td><td>0</td></tr>
</table>
* Calculated with validated default values for fertiliser production.

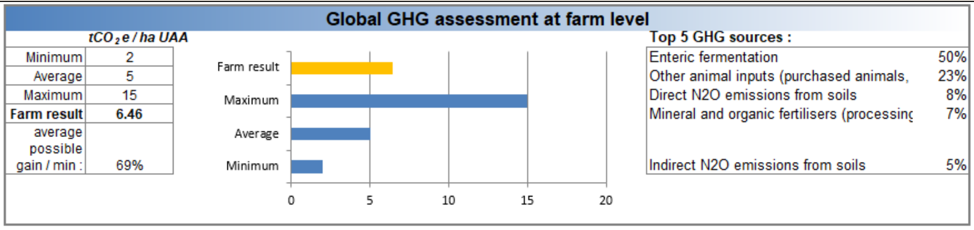
There is the function to compare results against previous activities, but it does not compare with benchmark data from other holdings.</td></tr>
</table>

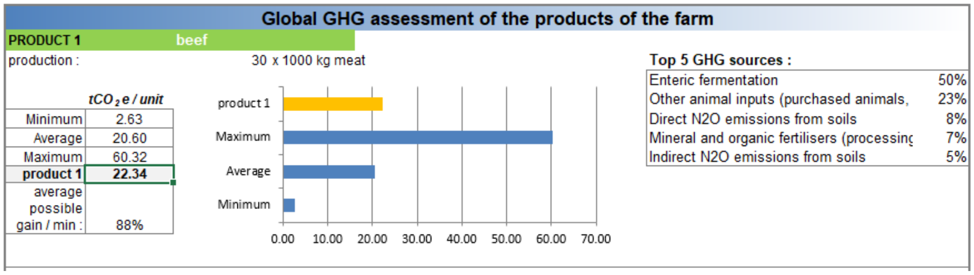
Table 10: Solagro Carbon Calculator test results – user experience

Attribute	Notes
User interface	The user interface is poor and not well designed. Non-experts in Excel were challenged with getting the settings right to run the Excel macros. The size of the data input windows that open from the ‘Home Page’ are not adjustable which is difficult when working on a small screen (such as on a laptop computer).

Attribute	Notes
Complexity for users	Other than the general problems with the user interface, there are no significant problems with the complexity of data input requirements; in some areas there is useful prepopulated information generated from geographic data sets, such as for soil and rainfall data.
Data Entry	The user identification has an issue that it does not include the UK as an option in the drop-down menu. This does not affect the results and in the next page the UK is offered as an option. Despite the basic interface the data entry is relatively intuitive and provides fields for all the required enterprises associated input data. These are structured as follows:  **User Identification:** Name and organisation **Assessment identification**: Products, climate/weather and farm details **Livestock:** • Offers a range of species • Livestock Numbers • Forage • Feed • Manure management **Cropland:** • Enter a range of crops • Enter details for fertilisers, pesticides, crop management, machinery operation and irrigation **Other inputs**: • Energy • Natural elements and land use change • Buildings • Organic matter flows • Secondary inputs • Machinery • Cooling and refrigerant
Gaps in emission or removal sources	The tool appears to capture all the required input data and goes further than the other tools on sequestration relating to hedgerows and other woody biomass, however, it is not clear how this information is used.
Reporting	Solagro CC provides highlevel results as presented below which detail the emissions per ha and emisssions intensity per tonne of beef (liveweight).

Attribute	Notes





The Solagro CC tool also provides detailed output in relation to the emissions by process, such as enteric fermentation and manure management as detailed below.

Detailed GHG emissions sources and carbon storage

Current situation (tonnes / year)	tCO_2	tCH_4	tN_20	tHFC (in CO_2e)	tCO_2e	
1 GHG emissions from direct activities	6.0	14.0	0.3	0.0	459.4	69%
1-1 Machines and equipment	6.0	0.0	0.0	0.0	6.0	1%
Mobile machines	6.0			0.0	6.0	1%
Fixed machines	0.0			0.0	0.0	0%
1-2 Process emissions	0.0	14.0	0.3		453.4	68%
Enteric fermentation		13.3			333.3	50%
Manure management		0.7	0.0		30.4	5%
Direct N_2O emissions from soils			0.2		54.1	8%
Indirect N_2O emissions from soils			0.1		35.6	5%
Crop residues burnt		0.0	0.0		0.0	0%
2 GHG emissions from indirect activities	206.0	0.0	0.0	0.0	206.0	31%
2-1 GHG emissions of energy used on the farm and purchased by thirds	1.0	0.0	0.0		1.0	0%
Electricity purchased (i.e. on the grid)	0.2				0.2	0%
Collective irrigation (electricity or fuel for pumping)	0.8				0.8	0%
Fuels from thirds (operations done by contractors)	0.0				0.0	0%
2-2 GHG emissions for other purchased inputs	204.9	0.0	0.0		204.9	31%
Mineral and organic fertilisers (processing and transportation)	43.6				43.6	7%
Other crop inputs (seeds, pesticides)	0.0				0.0	0%
Secondary inputs (plastics and other petrochemicals)	0.0				0.0	0%
Purchased feedstuff	5.5				5.5	1%
Other animal inputs (purchased animals, rearing costs)	153.0				153.0	23%

The tool also attempts to produce a measurement of the carbon stock change from grassland and other biomass inputs. However, there are questions on the reliability of these calculations that require further investigation with the developers.

11. Appendix 6 – Strengths, weaknesses, opportunities and threats (SWOT) tables for shortlisted tools

Analyses of strengths, weaknesses, opportunities and threats (SWOT) are presented for AgRE Calc, The Cool Farm Tool and Solagro CC, in Table 11, Table 12 and Table 13 respectively.

Table 11: AgRE Calc strengths, weaknesses, opportunities and threats (SWOT)

AgRE Calc	
Strengths	Weaknesses
• Simple, easy-to-use interface • Results are reported in multiple ways with useful breakdown. Provides clear GHG intensity values by enterprise. • Peer benchmarking capability	• Carbon sequestration estimates are not comprehensive • Fuel and energy usage data entry requires user allocation to enterprises, despite a small contribution to agriculture GHG emissions • Does not include embedded emissions in livestock bought in from another farm
Opportunities	Threats
• Benchmarking facility in reporting of results • Financial data gives insight for a farm business	• Ongoing availability of the tool. SAC are committed to providing the tool for the duration of the Beef Efficiency Scheme (end of 2021)

Table 12: Cool Farm Tool strengths, weaknesses, opportunities and threats (SWOT)

Cool Farm Tool	
Strengths	**Weaknesses**
• Visually appealing user interface • Relatively simple data entry • Reporting is easy to interpret for individual enterprise modules	• Will not provide a full enterprise GHG intensity figure for livestock as forage crops need to be calculated in a different module • Errors in labelling - e.g. grass module labelled as potato • Poor guidance provided which leads to some confusion and lack of transparency • Limited and unclear sequestration capability • Does not include embedded emissions in livestock bought in from another farm
Opportunities	**Threats**
• There may be opportunities to improve the aggregation of data • Improved guidance is in development	• Continuity of the service: it is supported by The Cool Farm Alliance with multiple funders, so risk is perceived as low

Table 13: Solagro CC strengths, weaknesses, opportunities and threats (SWOT)

Solagro CC	
Strengths	**Weaknesses**
• Well-documented assumptions and guidance • Excel based and can be run offline • Useful mitigation advice with quantified estimates • Good reporting structure	• Last updated in 2016 - low levels of ongoing support • The interface is not user-friendly • Annual carbon stock change appears to be overestimated (?) • Does not include embedded emissions in livestock bought in from another farm
Opportunities	**Threats**
• For development of the interface to make this a more user-friendly tool that can be used offline	• Continued lack of support

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